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The influence of canopy traits on throughfall and stemflow in five tropical trees growing in a Panamanian plantation

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Abstract

Tree canopies partition rainfall into temporary canopy storage, throughfall and stemflow. Knowledge of this partitioning process is needed to predict the hydrological effects of the large areas of tree plantations that are being established in the tropics. In this study, we compared throughfall, stemflow and interception in four Neotropical and one exotic tree species growing in selection trials in the Republic of Panama. We sought to answer four questions: (1) Are there interspecific differences in total throughfall and stemflow, and throughfall and stemflow for a range of rainfall depths?, (2) How do crown traits influence interspecific differences in throughfall?, (3) Does the spatial heterogeneity of throughfall differ among species? and (4) How do species affect litter biomass and other variables that influence rainfall erosivity? Rainfall depth mediated interspecific differences in throughfall and stemflow, the relative importance of crown traits in the interception process, and spatial heterogeneity of throughfall. Total throughfall was between 10.9 and 16.2% less in *Acacia mangium* than *Gliricidia sepium*, *Guazuma ulmifolia*, *Ochroma pyramidale* or *Pachira quinata*. Increasing rainfall also changed relative quantities of throughfall and stemflow among species. For example, throughfall was similar in *Gliricidia* and *Acacia* for small rain events, but increased more rapidly in *Gliricidia* with increasing rainfall depth. Interspecific differences in throughfall were driven, in part, by canopy traits. Leaf area index (LAI), crown depth and crown openness all affected throughfall from smaller storms, but live crown length was the only significant predictor of throughfall in storms that were deeper than 20 mm. The spatial heterogeneity of throughfall beneath individual tree canopies increased with rainfall depth, but was always lower in *Gliricidia* than in *Acacia*, *Ochroma*, or *Pachira*. High litter biomass and cover in *Acacia* and *Ochroma* relative to other species would be likely to buffer the erosive effects of raindrop impacts. These complex interactions between rainfall and species traits may affect local hydrology, and may need to be explicitly considered in reforestation projects in the seasonal tropics.

Keywords: Throughfall; Stemflow; Canopy traits; Neotropical tree species; *Acacia mangium*; Plantation forestry; Hydrological impacts

1. Introduction

1.1. Rainfall interception by trees

Tree canopies modify raindrop trajectories by partitioning the incident rainfall into throughfall and stemflow. A proportion of the incident rainfall is intercepted by, and retained temporarily on leaf surfaces, branches and stems. Some of this intercepted rainfall subsequently evaporates by a process known as ‘‘wet-canopy evaporation’’ or ‘‘interception-loss’’ (I_c). A second fraction, throughfall (T) either falls from foliage as ‘leaf-drip’ or passes directly through small gaps in the canopy as ‘direct throughfall’. A third component is channeled down side branches to the main stem as ‘stemflow’ (S) (Crockford and Richardson, 2000; Chappell et al., 2001). These components are linked by the following relationship:

$$I_c = P_g - T - S \quad (1)$$

where P_g stands for gross rainfall.

The species composition of vegetation cover and changes in land use affect the balance between throughfall, stemflow, interception and evapotranspiration (Brandt, 1987; Bonell, 1999; Douglas, 1999; Crockford and Richardson, 2000; Bruijnzeel, 2004,). These variables are modified by canopy cover, canopy architecture, and tree age in broadleaved and coniferous forests (e.g. Huber and Iroumé, 2001; Pypker et al., 2005), and agroforestry systems (Schroth et al., 1999). Leaf

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shape, orientation and size (Calder, 2001; Nanko et al., 2006), branch angle, leaf area index (LAI) and canopy gap fractions all play roles in rainfall partitioning (Crockford and Richardson, 2000; Johnson and Lehmann, 2006). Stemflow is influenced by canopy volume and area (Martinez-Meza and Whitford, 1996), and the angle at which branches join main stems (Iida et al., 2005). Bark roughness and absorptivity further modify stemflow by affecting the storage capacity of main stems and branches, which may exceed that of small branches and foliage combined (Herwitz, 1985; Liu, 1998; Llorens and Gallart, 2000; Levia and Herwitz, 2005).

1.2. Role of plantations in local hydrology

Forest plantations and agroforestry are increasingly seen as viable land use alternatives on deforested and degraded lands in the tropics (Evans, 1999; Lamb, 1998; Cusack and Montagnini, 2004). If established over wide areas, tree plantations are likely to produce major alterations in watershed- and landscape-scale hydrology. Reforestation of whole watersheds generally leads to reduced dry season water flows (Jackson et al., 2005; Scott et al., 2005; Sun et al., 2006). Relative to grass cover or cropland, tree cover increases rainfall interception (e.g. Dunisch et al., 2003), but improves the infiltration of water into the soil, and limits evaporation from the soil (Wallace et al., 2005). Raindrop erosivity is also reduced because litter inputs directly protect the soil surface and improve soil structure (Wiersum, 1985; Brandt, 1987; Mapa, 1995; Putuhena and Cordery, 1996).

Planted trees might improve soil moisture and overall water yields if improved infiltration and reductions in soil evaporation were to exceed any additional losses due to evapotranspiration (Scott et al., 2005). Most interception studies in the tropics have, however, been done in unmanaged or lightly managed natural forests with multiple species and canopy layers (Chappell et al., 2001; Germer et al., 2006). By contrast, *Pinus* and *Eucalyptus* are the most frequently investigated genera in plantation-based interception studies (reviewed in Scott et al., 2005). Our knowledge of rainfall interception among tropical broadleaved tree species in plantation is derived from isolated studies of *Acacia auriculiformis* A. Cunn. (Wiersum, 1985), teak (*Tectona grandis* L.f.) (Calder, 2001), *Carapa guianensis* Aubl. (Dunisch et al., 2003), shade coffee plantations (Hairiah et al., 2006), and agroforestry systems (e.g. Imbach et al., 1989; Schroth et al., 1999). As the area of tropical plantations expands, and the number of species being grown in plantations increases, more studies of the effects of tropical plantations on rainfall interception and other aspects of local hydrology are needed.

1.3. Objectives and research questions

The purpose of our research was to investigate interspecific differences in the dynamics of throughfall and stemflow among plantation-grown tropical trees. Five species were chosen for study based on differences in their trunk and branch architecture, leaf size and arrangement and crown morphology. Data on throughfall and stemflow were collected from individual trees over 2 months to answer four questions: (1) Are there interspecific differences in total throughfall and stemflow, and throughfall and stemflow for a range of rainfall depths?, (2) How do crown traits influence interspecific differences in throughfall?, (3) Does the spatial heterogeneity of throughfall differ among species? and (4) How do species affect litter biomass and other variables that influence rainfall erosivity?

2. Methods

2.1. Site descriptions

Our study was conducted in an experimental multi-species tropical forest plantation located in Soberania National Park (SNP), Republic of Panama (9°10′N, 79°35′W). The natural vegetation in SNP is lowland tropical moist forest, in which annual rainfall, averaged over the period 1966–2003, was 2127 mm yr^{-1} with a 4-month dry season in which less than 100 mm of rain fell in each month (Autoridad Nacional del Ambiente, unpublished data). Most rain events are short but intense storms, with occasional longer events of moderate intensity. The topography of the planted area comprises rolling hills with slopes of up to 48% interspersed with occasional moist swales.

The plantation was established by the Project for Reforestation Using Native Species (PRORENA), a joint project of the Smithsonian Tropical Research Institute (STRI) and Yale Tropical Resources Institute (TRI). It comprises a series of species selection trials intended to demonstrate the feasibility of using native and exotic trees to restore forest cover to degraded agricultural land. At SNP, 63 native and exotic species pre-selected for their restoration potential, timber value, fodder production, live fencing and fruit production were planted between 2003 and 2005. Each specie was planted in three replicate monocultures of 20 trees in each of three randomized complete blocks at 3 m × 3 m spacing. At 2 years of age, half the trees in each plot were thinned to avoid crown competition, increasing inter-tree spacing to 6 m × 6 m.

2.2. Species selection

Tree species chosen for the measurement of throughfall and interception were selected on the basis of obvious differences in crown architecture, leaf size and arrangement and stem morphology (Table 1, Fig. 1). In addition to these morphological criteria, the crowns of neighboring trees had to be in contact, or nearly so, and only plots that had attained an average crown closure of 60% or greater were chosen for study. This metric was estimated by looking upwards through a 10 × 10 grid of 2 cm squares drawn on clear plastic and estimating closure by the grid at four random points. The species chosen were *Acacia mangium* Willd., *Gliricidia sepium* Jacq., *Guazuma ulmifolia* Lam., *Ochroma pyramidale* Swartz, and *Pachira quinata* (Jacq.) W.S. Alverson. All of these trees (hereafter described by their genus names only) have